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Expanded Thermoplastic Core: A New Dimension in Plastics for Structural Applications

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THE ORIGINAL RESEARCH AND INVENTION of the Expanded Core Process was done by Walter Smarook at Union Carbide's Bound Brook Laboratory. Norfield Corporation has subsequently developed the process to a commercial scale and is the sole licensee of this new plastic technology, which is documented by Carbide's United States patent 3,765,810, several foreign patents, and a series of patent applications. A novel feature of this new plastic fabrication method is its ability to provide honeycomb-like structures of high strength-to-weight ratio from a variety of thermoplastics, which cannot be duplicated by any other known technology short of hand carving.

Expanded Core products, compared to other honeycomb structures, have the following unique combination of features:

1. Integral faces to provide rigidity and flexural strength without post lamination.
2. Barrier to liquids or gases as each cell is an interlocked closed cone rather than an open column.
3. Undercut cells for mechanical locking of mastic and cement of plaster type materials.
4. Wide variety of plastic compositions tailored for mechanical, electrical, chemical, fire resistant, and thermal stability properties.
5. Available in decorative, transparent, virtually any color, and numerous filler combinations.
6. Large face area for bonding where skins are desired for greater strength or decorative effect.

Variations of the fundamental process permit hundreds of distinctly different products, including but not limited to honeycomb cores. Applications range from simple decorative free-standing partitions systems to chemical tanks, truck-bodies, energy attenuators, and concrete forms.

CORE DEVELOPMENT HISTORY AND THEORY

In his original work which led to the invention of the Expanded Core Process, Mr. Smarook took advantage of principles observed at Bell Laboratories some seven or eight years ago—because of surface energy relationships, polymers when heated to a molten state will adhere to surfaces from which they will release when cooled. Almost everyone who has worked with hot plastics had observed, and perhaps cursed the hot sticking phenomenon. What Smarook did was to utilize this nuisance property in a useful way. Not so obvious even to plastics engineers is that polymers will adhere when hot to metal molds even when they have been coated with Teflon release agent. The Expanded Core process works with almost all thermoplastics. Thus the basic principle and novelty of the process lies in the fundamental property of hot tack adhesion of polymers. Above their melt temperature, or glass transition of amorphous materials, polymers will stick to all substrates irrespective of the surface energies of the adherends. These surfaces may be ceramic, metal or high

ABSTRACT

This paper deals with the development of a new plastic fabrication method, the Expanded Core process. The resultant products of this process have many unique combinations of features in comparison to other honeycomb structures.

This new process, with variations, lends itself to numerous applications. Its chief advantage lies in the fact that low pressures are required which results in low capital costs.

temperature polymers. Some polymers such as polypropylene and polyethylene lose their adhesion to these surfaces on cooling but other plastics need to be made to release through pretreatment of the molds with mold release agent. So if a polymer in sheet form is placed between two properly heated surfaces and the molds are then pulled apart in a controlled fashion, it is possible to obtain polymer flow and thus the formation of a geometric structure without losing the adhesion to the mold surfaces. This occurs because the adhesive forces of the polymer to the mold are stronger than its cohesive force. Utilization of this principle then permits a variety of geometric patterns of the molds such as round, square, hexagonal, triangular, and diamond shaped for each of the mold surfaces or flat on one side and patterned on the other. Each of these mold patterns will affect the formation of the plastic structure in an ordered, near vertical webbing during separation. To eliminate the tendency of each cell to form a partial vacuum chamber during expansion and thus running the risk of the differential pressure puncturing the cell walls, each mold cell is vented to the atmosphere. Mr. Walter Smarook refined this technology over several years using a variety of mold patterns and representative grades of most thermoplastics.

In 1972, Norfield was granted an exclusive license for the United States and nonexclusive abroad from Union Carbide to develop this technology further and to commercialize applications based on a new family of cellular plastic structures. Norfield's first commercial installation was established in Danbury, Connecticut in 1973 and full operation achieved in 1974. Equipment was designed to produce core in sheet sizes of up to 4 × 10 ft and in a range of thicknesses from ¼ in to 8 or 10 in depending on the particular plastic used. Commercial cores have been made from ABS, Acrylic, Polycarbonate, Polypropylene, Polystyrene, PVC, Noryl, Surlyn, and UVEX, with and without fillers and pigments. As with conventional honeycomb, high-strength sandwich panels can be fabricated with a variety of faces. Unlike a typical honeycomb structure though, the Expanded Core product has structural integrity without post lamination by virtue of its having a surface area about the periphery of each open cell. Each face section is not continuous but has a series of staggered holes. A cross section of the structure would reveal a somewhat typical I-beam section with a web portion resembling V trusses. This feature imparts structural strength at low core densities and consequently offers new concepts in engineering design and decorative effect, where emphasis is placed on light weight structures and innovation.

Since each cell is an interlocked, closed cone rather than an open column, the core may be used as a barrier to gases and liquids, or used to mechanically lock materials such as cement, mastic or plaster, thus the functioning as a lath structure.

Since the ultimate physical properties of Nor-Core structures depend on both the nature of the polymer selected and the final bulk density, a host of different end products tailored for mechanical, electrical, chemical, fire resistant, thermal stability and decorative properties may be produced with essentially the same processing equipment. Skin formation during expansion is determined by adhesive flow, which tends to remain fairly constant in thickness regardless of expansion height, while web formation on the other hand is determined by the cohesive flow during expansion and decreases in thickness almost in a linear function with expansion height. Thus for each plastic sheet of a given starting thickness, an optimum expansion-to-strength ratio is achieved. If expanded beyond the optimum, web walls get thinner and thinner until they form holes and lose strength.

The Expanded Core Process yields complete structures without further modifications. By way of illustration, compare the functionality of a typical steel I-beam structure or of a composite foam core laminate with the Expanded Core structure. With I-beams, greater rigidity can be achieved by increasing beam height to thickness. Similarly, for a composite structure consisting of a foamed core with laminated faces on each side, the rigidity can be increased by using thicker and/or higher modulus faces or by increasing either foam density or foam height at constant density. However, in the Expanded Core Process it is not possible to increase web thickness while increasing the expansion height of the polymer. As the mold surfaces are separated, the quantity of the adhering polymer remains fairly constant but the web thickness decreases more and more since no additional polymer is added during the operation. Thus, skin and web thickness relationships are determined by the balance of adhesive and cohesive flow properties of the polymer and the expansion ratio (final core thickness : starting sheet thickness). Since skin thickness is limited, it will also limit the value of the moment of inertia of the structure, and thereby, its stiffness. Increased flexural rigidity may be obtained by adding material to the faces through post lamination or increasing web thickness by using a thicker starting sheet. Since the core has a larger skin area (as compared with conventional honeycomb), the structural performance for distributing axial loading and tensile strength is improved and at the same time also provides a large surface for bonding.

Density, modulus, flexural and impact resistance can be changed through polymer selection, expansion ratio and initial sheet thickness. Expanded core structures are efficient energy absorbers. Under moderate impact, energy is absorbed by the web structure and will fully recover up to its elastic limit; beyond this a second level of energy absorption is obtained from web crushing. Unlike foam and wood cores, high localized impact does not result in fracture propagation, thus restricting destruction to a localized area which is more easily repaired. When the open core is exposed, the standard core geometry functions as an effective sound trap. Sound absorptions in the range of 40-60% have been recorded in the 1200-6000 Hz range.

Intuitively one would expect the core to have thermal insulation value. Only limited testing has been done to date, which confirmed the core to have a K factor similar to wood—about 0.7 for a 3/4 in Impact Polystyrene Core with a 4.5 lb/ft^3 density. This is of course higher than common closed cell forms, but substantially lower than many other structural

materials. Where the core is to be post laminated, it is expected that considerable insulation factor improvement can be made by filling the core cells with low density foams or vermiculite.

The most critical structural property for most panel construction applications is flexural strength. A wide range of values can be obtained depending upon core thickness, density, facing material selection, and to a lesser extent the selection of plastic used in the core. According to simple beam loading tests performed by Norfield, it is possible to obtain flexural strengths to weight ratios in the range of four times that obtained for 3/4 in plywood.

Detailed test data can be found in the appendix.

TRANSPORTATION

Prime requisites for large cargo containers include high strength at minimum weight for static load capacity plus localized and general impact resistance. Present approaches utilize a variety of sandwich construction techniques where aluminum skins are bonded to either paper honeycomb or urethane foam. However, foam cores are inherently weak structurally and frequently form unacceptable bonds. Paper honeycomb on the other hand are susceptible to water damage if the skins get punctured and due to the small contact area delamination of the faces can easily occur. Norfield is working on the development of a panel system for use in cargo containers and truck bodies, and ultimately hopes to participate in the Military Shelter program. This shelter program can extend to complete military, hospital, school or emergency shelter installations. Laminated panels using Nor-Core have been tested and found to be 2-3 times stronger than 3/4 in plywood at half the weight. For the transportation industry, this is significant since weight savings increase payload and reduce fuel consumption. In the aircraft field, Nor-Core panels are also being considered for use as flooring, doors and dividers.

CONCLUSION

As a commercial reality, the Expanded Core Process is in its infancy. The original research by Walter Smarook of Union Carbide resulted in basic patent filings in December of 1971. Norfield began developing information for commercial equipment during the second half of 1972 and made the first 4 X 10 ft Polypropylene core in December of 1973. Translating this experience to other plastics required a separate development program and a series of milestones during 1974 and into the present. Problems which seemed nearly insurmountable a year ago are second nature now. The process is exceedingly simple in concept, yet as with most any technology, it only works when done right. We used to think of our big green machine as a "violin," but after each day of experience it is beginning to behave more like a "player piano."

Compared to other methods of achieving three-dimensional plastic structures, perhaps the chief advantage of the Expanded Core Process is that low pressures are required, which means that capital costs are relatively low. As additional markets are developed, small batch operations can be set up in proximity to the user in order to reduce freight costs. The ultimate economic potential, however, lies in integration of the process to an in-line extruder. When this is done, it is believed that Expanded Core can be produced at a cost nearly competitive with simple flat extruded sheet. The economic efficiency of Expanded Core can then perhaps best be seen by comparing the advantages of an I-beam to a simple prismatic bar.

For those of us directly involved in the Expanded Core Process development, the most exciting aspect is working with creative customers. For every application we can think of, there are at least ten out there with even better ideas. We have described a few applications which are in commercial use and/or under serious consideration. By the time we get into print, there will be more new uses and more proven experience.

REFERENCE

1. Walter H. Smarook, "Expanded Cores; Structural Plastics, The Easy Way." Plastics Engineering, August 1973.

APPENDIX A

Plastic	Core Thickness (in)	Nominal Density (lb/ft^3)	Compressive (psi) (Stabilized)	Comp Modulus (psi)	Flat Tensile (psi)	Tensile Modulus (psi)	Shear Stress (psi)	Shear Modulus (psi)
Polyvinylchloride	1.0	6.6	73	3,700	160	12,583	93	3,563
	0.9	9.73	179	9,488	212	16,100	100	9,666
	1.0	11.2	162	3,956	174	21,910	94	4,840
	0.48	10.46	228	12,000	232		140	1,257
	0.60	8.37	128	7,700	200		122	1,229
	0.72	6.97			177			
	0.84	5.98	32	2,100	158		96	1,046
	0.8	10.4	306		213		96	1,770
	1.0	8.3	209					
	1.2	6.9	140		128		37	1,000
	1.4	5.9	45		120		31	875
Polycarbonate	0.9	7.24	69	11,666	251	12,562	79	3,260
	1.1	8.58	211	21,366	294	18,275	161	7,066
	1.2	9.45	250	26,333	304	52,500	139	9,030
Impact styrene	1.05	6.3	50		89	3,650	34	
	1.26	5.3	117		58	3,150	32	
	1.47	4.5	187		33	2,800	8	
	0.84	7.9			138	4,550	57	
Polypropylene	1.1	4.8	25		128	12,892	15	784
	0.9	5.8	56	6,158	177	12,638	14	416
	1.2	7.38	148	15,479	256	30,409	19.5	916
	0.92	7.6	169	3,350				
	1.15	6.2	94	2,250				
	1.38	5.3	74					
	1.61	4.4	56	1,350				
ABS	1.00	6.15	58		133			
	1.00	6.66	74		136			
	1.00	8.15	192		248			
SAN	0.8	8.52	239	15,300				
	1.00	6.81	171					
	1.2	5.68	138	7,950				
	1.4	4.87	120	6,150				
Polyethylene	0.4	6.93	72		125		51	
	0.5	5.54	39		115		48	
	0.6	4.64	16		82		31	
	0.7	3.81	7		49		20	
Polyetidylene	0.8	7.66	160		222		134	
	1.0	6.16	128		170		52	
	1.2	5.12	92		132		35	
	1.4	4.19	45		102		16	
	1.04	7.00			207			
	1.30	5.76			142			
	1.56	4.81			105			
	1.82	4.12			78			
Nylon	1.2	5.8	80		175		73	
	1.8	8.7	240		240		114	
	1.1	11.0	420		270		130	

APPENDIX B

NOR-CORE PANEL DEFLECTION LOAD TESTS

Norfield Core, Nor-Core, is a honeycomb like material in panel form. Unlike conventional honeycomb, Nor-Core panels are rigid self-supporting structures as produced. However, in many applications, additional flexural strength is desired and can be obtained by laminating faces to one or both sides of the core. Nor-Core is produced from a variety of thermoplastics in a wide range of thicknesses and densities, the result being an array of products with differing moments of inertia. To assist the engineer in selection and design of optimum structural systems where horizontal panels are loaded to

Table B-1 – Flexural Load Tests

Core Weight (lb/ft^2)	Core (in)	Top Face (in)	Bot. Face (in)	Total (in)	Total Load (lb)	E I Calc. ($lb\text{-}in^2 \times 10^5$)
			Core – Impact styrene/Face – Impact styrene			
1.05	0.50	0.125	0.125	0.75	150	1.46
1.05	0.75	0.125	0.125	1.00	250	2.43
1.05	1.00	0.125	0.125	1.25	350	3.40
1.05	1.25	0.125	0.125	1.50	480	4.66
1.05	1.50	0.125	0.125	1.75	580	5.64
			Core – Polycarbonate/Face – None			
0.78	1.00	None	None	1.00	70	0.68
0.78	1.56	None	None	1.56	125	1.23
			Core – Polycarbonate/Face – Polycarbonate			
0.78	1.00	0.125	0.125	1.25	350	3.40
0.78	1.00	0.100	0.100	1.20	315	3.06
0.78	1.00	0.080	1.100	1.18	315	3.06
0.78	1.00	0.100	0.080	1.18	290	2.82
0.78	1.00	0.125	None	1.13	140	1.36
0.78	1.00	None	0.125	1.13	140	1.36
0.78	1.56	0.100	0.100	1.76	315	3.06
0.78	1.56	0.125	0.125	1.81	410	3.98
0.78	1.56	0.125	None	1.68	190	1.85
0.78	1.56	None	0.125	1.68	185	1.80
			Core – Polycarbonate/Face – Cast acrylic			
0.78	1.00	0.063	0.063	1.13	260	2.53
0.78	1.56	0.063	0.063	1.68	300	3.01
0.78	1.56	0.125	0.125	1.81	450	4.38
0.78	1.56	0.125	None	1.68	210	2.04
0.78	1.56	None	0.125	1.68	175	1.70
			Core – Polycarbonate/Face – Pressure laminate (Formica)			
0.78	1.56	0.063	0.063	1.68	515	5.00
			Core – PVC (Airco)/Face – PVC (Airco)			
0,89	1.00	0.125	0.125	1.25	210	2.04
0.89	1.50	0.125	0.125	1.75	140	1.36
			Core – Polypropylene/Face – Polypropylene			
0.89	1.94	0.125	0.125	2.14	295	2.86
0.89	1.94	0.125	None	2.07	150	1.46
0.89	1.94	None	None	1.94	120	1.19
			Core – Polypropylene/Face – Aluminum			
0.89	1.88	0.032	0.032	1.94	900	8.75

a specific deflection criteria, Norfield has conducted a series of simple comparative tests on a variety of panel systems. The results are presented below.

The test method employed was devised by Norfield and does not purport to conform to standard industry practice. Ultimate user designs should be tested under conditions more nearly approximating actual service conditions. Nevertheless, we believe the data presented will provide a useful starting point to select systems for further testing.

In the Norfield tests (Fig. 1) 12 X 24 in panels were Center loaded using a hand-operated hydraulic jack, equipped with an oil pressure gauge. The load point was a steel bar across the 12 in width with a force to deflect panels 1/8 in over an 18 in span of two freely supported fulcrum bars parallel to the load

bar. Calculations were based on the assumption of a simple 12 in wide beam using the formulas:

$$\text{deflection} = \frac{P\ell^3}{48\,EI} = \frac{5w\ell^4}{384\,EI}\text{; all units inches and pounds}$$

Note: Data presented is consistent with model; however, actual loads were applied upside down to facilitate practical use of jack.

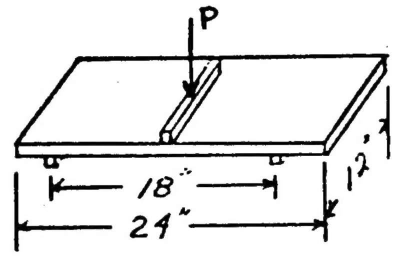

Fig. 1 – Test model

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